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CFD SIMULATION AND FIELD DATA ASSESSMENT OF OPEN PAN JAGGERY MAKING FURNACE

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ABSTRACT

Jaggery is India's traditional sweetener prepared from sugar cane. Jaggery has many health benefits compared to white sugar and is produced by the concentration of sugarcane juice heating at elevated temperature. Bagasse is obtained after crushing of sugar cane which is used as fuel in the furnace producing jaggery. The modeling and simulation of heat transfer between the combustion gases and the juice are very important in order to improve the thermal efficiency of the process. It enables to understand with a high level of detail the heat transfer phenomenon occurring from bagasse combustion flue gases to sugarcane juice. This paper presents the results of the CFD modeling and simulation of heat transfer phenomenon in the open pan jaggery furnace and those results are compared with field measured data. Numerical results about temperature variation of sugarcane juice and Flue Gases with time are in good agreement with field measurements, validating the predictive capacity that CFD model offer in the detailed representation of the fluid flow and heat transfer characteristics of such a furnace, which will help in the design of thermal efficient furnace to increase heat utilization for boiling of juice and jaggery production.

***KEYWORDS:** Bagasse, Jaggery, Single Pan, CFD & Flue Gases*

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Original Article

INTRODUCTION

India is the largest consumer and the second largest procedure of sugar in the world [7]. Presently, sugarcane is cultivated in an area of about 4 million hectares of land in India, producing about 250-300 million tons of sugarcane annually, out of which 35% is crushed for jaggery preparation. Jaggery (Gur) is a traditional sweetener which is produced from sugar cane. Jaggery is produced by the concentration of sugarcane juice by evaporating water by boiling off sugar cane juice. It has been and will continue to be an important sweetening agent in the various food preparations due to its peculiar taste and nutritional value. Jaggery contains 65-85% sucrose, 10-15% reducing sugars, 3-10% moisture and the remaining (in traces) made of other insoluble matter such as fat, proteins, minerals, iron, and phosphorus [5]. As per the survey of jaggery industry in India, jaggery production was 10.3 million tons in the year 2000 in western Maharashtra especially in Kolhapur, the cane production is significant and the jaggery made from some special sugarcane varieties such as Co-92005, Co-8014, and Co-86032 etc. has good demand in the national and international market. Jaggery making is typically a rural and small-scale enterprise owned & manned by furnace creating employment opportunities to the millions of people in rural areas. Studies made by various researchers [5] clearly indicate that there is need of considerable improvement in the energy efficiency of the jaggery making process. The increase in the jaggery energy efficiency can be achieved through the construction of new thermal efficient jaggery processing units or by the modernization

of existing ones. Further increase in energy efficiency of the jaggery making process would result in to increase in jaggery production and saving of bagasse. The saved bagasse can be used in other useful applications such as paper and pulp industry, mushroom growing, as a fuel and for the production of ethanol, n-butane etc. thus leading to additional income to the farmers involved in this activity. As for optimizing the energy utilized for the jaggery making the process more iteration should be studied experimentally which is an uneconomical solution and time seeking a job, therefore the tools like finite volume modeling considering the dynamic behavior of multiphase physics process can be done in CFD.

RELATED WORK

Few research works were found concerning the application of CFD and /or experimental measurements for the study of the heat transfer phenomenon in the process of jaggery making developed an experimental work concerning the use of multi-pan method for jaggery making process improving the thermal efficiency [5]. Conducted experimental and numerical study about the determination of the thermal performance of a traditional jaggery furnace. For the numerical study, the authors utilized the mass and energy balances in order to calculate the energy loss stream. The results obtained indicated that the minimum energy required for the jaggery processing was estimated to be only 29% of the total energy supplied from bagasse consumption.[1] Analyzed, through field data analysis and experimental work, the thermal performance of two single pan and one four pan jaggery making units. The set of measurement included bagasse addition rate, total duration of the batch, sugar and water content in the cane, flue gas temperatures at three locations of the furnace, dry bagasse properties, moisture content, calorific value, proximate and ultimate analysis. Numerical results and field data measurement showed that the air flow rate strongly influences on the flue gas temperature and the burning efficiency. For instance a very low draft results in inefficient bagasse combustion causing low heat transfer. Its draft is high, there will be more air entering the furnace, which results in a reduction of the flue gas temperature and hence, the thermal efficiency. Further, it is also repeated from the measured use of multi pan method for jaggery making do not show considerable importance in thermal efficiency.

A thorough investigation was performed by [3] which involved the development of a 3D CFD model, simulation and field data assessment in the heat transfer study in five pan open heat exchangers used in jaggery production modules. Numerical results indicated a temperature drop of flue gases in the several locations of the jaggery furnace are in good accordance with field measurements. To the best knowledge of the authors, there is not a scientific study of any single pan jaggery making furnace that considers simultaneously the heat transfer phenomenon among flue gases, pan and sugarcane juice. The present work is devoted to the study of the heat transfer of a single open pan jaggery furnace installed in Kolhapur district of Maharashtra, Typically, all jaggery making plant in Kolhapur district of Maharashtra, use single open pan jaggery making furnace for jaggery making.

FIELD DATA MEASUREMENTS

For the validation of the 3D CFD model a field data was acquired using various instruments given in **Table 1.**

Table 1: Instruments used to collect Field Data

Sr. No	Instrument Type	Operating Range	Target
1	Spring Balance	0-25 kg	Bagasse weight
2	Weigh bridge	0-5tonn	Sugarcane weight
3	K type thermo Couple	0-1250^{0}c	Flue gases temperature
4	RTD sensor	0-200^{0}c	Sugarcane juice temperature

Table 1: Contd.,			
5	Refract meter	0-90^{0}BX	Sugarcane juice
6	Gas analyzer equipment	-	Flue gases composition and velocity

Four the flue gas temperature measurements 2 thermocouples were installed one on furnace wall and another on top of the chimney. RTD Sensor was used to measure temperature of sugarcane juice. Flue gas velocity and composition were obtained manually with the Green Tech stack sampler GSS-121, the sampling probe was placed in the interior of the chimney Brix measurement were conducted manually by removing sugar cane juice from an open pan.

CFD MODEL

Single pan jaggery furnace geometric details are given as below and model developed in **Figure 1(a) (b),** Modelling of air flow, flue gas, sugar cane juice fluid domain and pan was done in ANSYS design modeler.

Dimensions of Furnace

Diameter of furnace - 2.77 m

Height of furnace - 1.52 m

Air Holes

No. of air holes - 8 Nos

Length air holes - 0.82 m

2 air holes of size - 0.15 m

6 air holes of size - 0.076 m

Baggase feeding hole of diameter - 0.254 m

Dimensions of Pan

Bottom diameter of pan - 3.00 m

Top diameter of pan - 3.40 m

Height of pan - 0.91 m

Dimensions of Chimney

Height of chimney - 4.26 m

Bottom diameter of chimney - 0.76 m

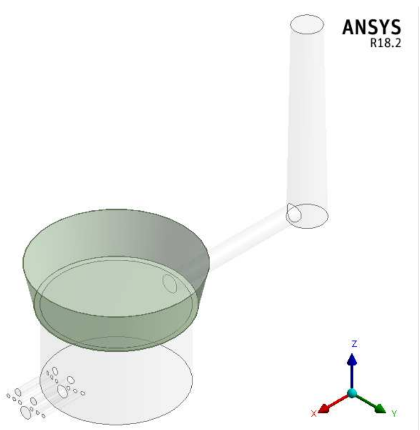
Top diameter of chimney - 0.60 m

Dimensions of Cooling Tray

Dimensions of cooling tray - 3m X 3m

The **Figure 1 (a), (b)** shows meshed model. Mesh quality was kept fine enough for putting it as input for Ansys Fluent. Cell count in the model was tried to be kept low due to challenge on computational time, but considering the

accuracy of geometry captured is maintained. The mesh model is having 371487 tetrahedral elements. The meshed model was analyzed using Ansys Fluent solver. Incompressible RANS equations were solved in fluent with standard K-Ɛ model for the turbulence modelling.



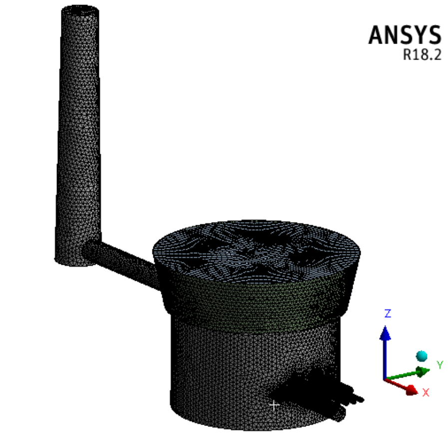


Figure 1 (a): Modelling in ANSYS FLUENT **Figure 1 (b): Meshing in ANSYS FLUENT**

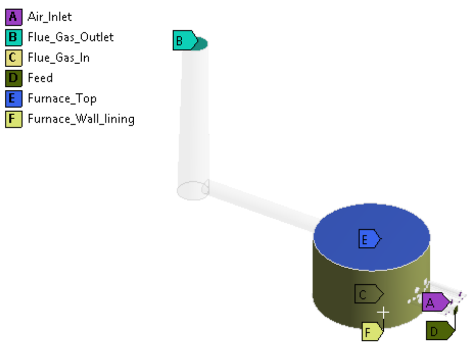


Figure 1(c): Boundary Conditions in ANSYS FLUENT

Setting Up Boundary Conditions

Considering actual model air openings, fuel inlets, flue gas outlets are marked for reference to be used in Fluent. **Figure 1 (c)** describes the different zones. For flue gases the bottom of the furnace is being applied with mixed type of thermal condition of convection and radiation (surface to surface) as this face contributes for view factor calculations. For flue gas outlet at chimney the ambient pressure and temperature was applied.

Solution Method

In solution method SIMPLEC scheme was used to solve the set of equations with a skewness correction of 1. Other parameters are kept with default setting. A hybrid type of initialization was used to set up a model and check for all input corrections. For calculation step size of 1 Sec with 7200 steps with each step iteration of 120 was used to complete 120 minutes. Cycle of one batch of sugar cane to jaggery solution convergence for 120 minutes (7200 sec) took 538890 iterations required to complete given end step with 12 cores on Xeon E5 series processor.

COMPARISON OF FIELD DATA AND CFD RESULTS

CFD approach was used to simulate flow of gases for the furnace to chimney **Figure 2(a),** sows streamline thermal distribution of fine gases. At midplane the thermal distribution of sugarcane juice was observed figure 4 shows the thermal distribution for sugarcane juice at midpoint.

Figure 2 (b) shows the temperature variation of sugarcane juice and the flue gases with time respectively. The results obtained using CFD analysis and field data measurements are in good agreement with a variation of 8.68% on average for sugarcane and 5.67% average for flue gases.

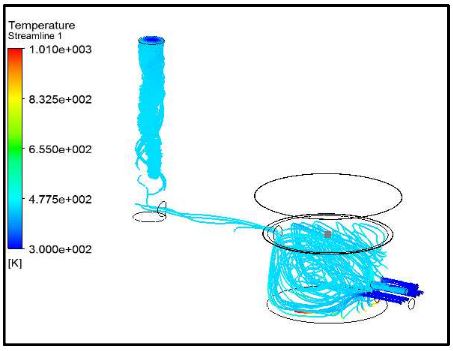


Figure 2(a): Temperature of Flue Gases

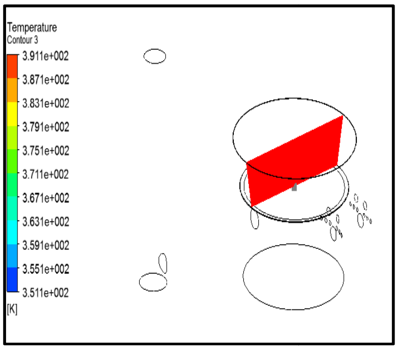


Figure 2(b): Temperature of Juice

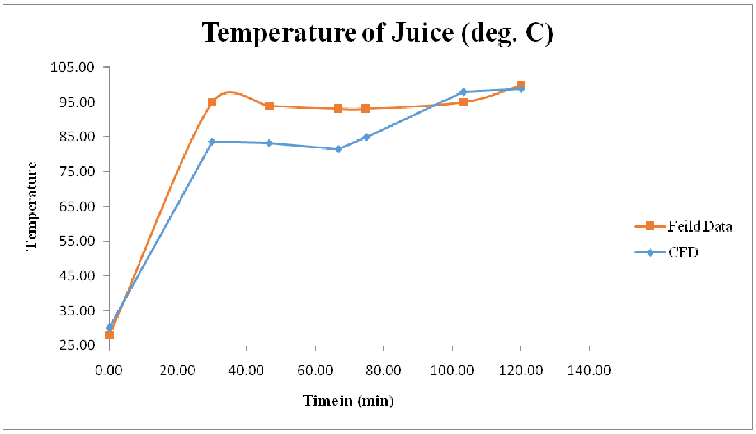


Figure 3: Temperature of Juice

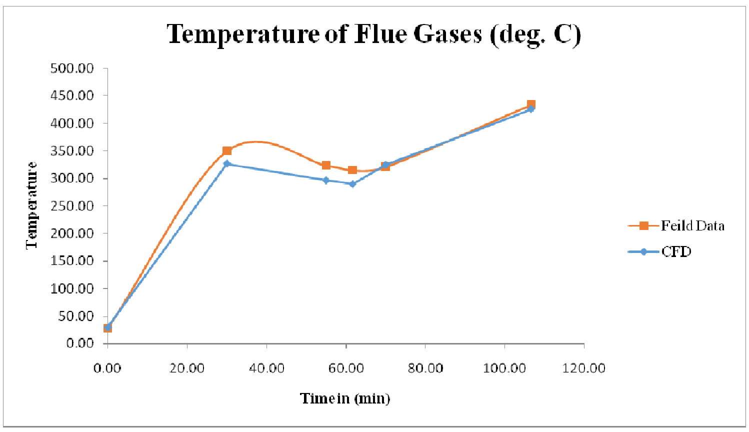


Figure 4: Temperature of Flue Gases

Figure 3, 4 shows the temperature variation of sugarcane juice and the flue gases with time respectively. The results obtained using CFD analysis and field data measurements are in good agreement with a variation of 8.68% on average for sugarcane and 5.67% average for flue gases.

CONCLUSIONS

Finally, it can be concluded that the CFD simulation tool can be used for analysis of jaggery making furnace with various improvements in existing plants such as the use of fire bricks for furnace construction, the design of improved pan for juice heating to develop thermal efficient furnace.

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